HURRICANE PROTECTION PROJECT

FOX POINT

HURRICANE BARRIER

PROVIDENCE RIVER, PROVIDENCE, RHODE ISLAND

DESIGN MEMORANDUM NO. 4

HURRICANE TIDAL HYDRAULICS

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

JANUARY 1960

U. S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM 54, MASS.

JDRESS REPLY TO:
IVISION ENGINEER

EFER TO FILE NO. NEDGW

29 January 1960

SUBJECT: Fox Point Hurricane Barrier, Providence, Rhode Island, Design Memorandum No. 4, Hurricane Tidal Hydraulics

TO: Chief of Engineers
Department of the Army
Washington, D. C.
ATTENTION: ENGWE

In accordance with EM 1110-2-1150 there is submitted for review and approval Design Memorandum No. 4, Hurricane Tidal Hydraulics, for the Fox Point Hurricane Barrier, Providence, Rhode Island.

FOR THE DIVISION ENGINEER:

John Wm Leslie

JOHN WM. LESLIE
Chief, Engineering Division

Incl. (10 cys)
Design Memo No. 4, Hurricane Tidal Hydraulics, Fox Point Hurricane Barrier

FOX POINT HURRICANE BARRIER
PROVIDENCE
RHODE ISLAND

DESIGN MEMO NO. 4

HURRICANE TIDAL HYDRAULICS

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1	Geology	9 October 1959	6 November 1959
2	Hydrology		
	Preliminary	3 June 1959	8 June 1959
	Final	17 November 1959	21 December 1959
3	Deleted		
4	Hurricane Tidal Hydraulics	29 January 1960	
5	General Design Memo	22 December 1959	
6	Embankment & Foundations		
7	Structural Section I		
8	Structural Section II		
9	River Gates	28 January 1960	
10	Pumping Station	22 January 1960	
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12	Sewer & Utility Modifications	29 January 1960	
13	Providence Cooling Water and Corrosion Considerations	8 January 1960	
14	Concrete Materials	3 November 1959	27 November 1959

FOX POINT HURRICANE BARRIER
PROVIDENCE RIVER
RHODE ISLAND

DESIGN MEMORANDUM NO. 4

HURRICANE TIDAL HYDRAULICS

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PROVIDENCE RIVER
RHODE ISLAND

DESIGN MEMORANDUM NO. 4

HURRICANE TIDAL HYDRAULICS

JANUARY 1960

A. GENERAL

1. Purpose. - The purpose of this memorandum is to determine the maximum tidal flood levels for design of the Fox Point Hurricane Barrier with associated wave heights, overtopping and run-up. Frequency of flooding is also developed.

B. NORMAL CONDITIONS IN NARRAGANSETT BAY

2. Description. - Narragansett Bay reaches inland about 26 miles in a northerly direction from the ocean to Providence, and has a water area, including Mount Hope Bay and the Sakonnet River, of approximately 140 square miles. The width of the bay across the mouths of the East and West Passages is 4 miles, and across the mouth of the Sakonnet River at Sachuest Point, slightly over 2.5 miles. The widest stretch of the bay is just south of Prudence Island where there is close to 6 miles of open water. Depths range from 50 feet in the lower West Passage, 160 feet in the East Passage, and 50 feet at the mouth of the Sakonnet River to shallow and shoal water in the innumerable small inlets and indentations in the Upper Bay. South of Narragansett Bay is Rhode Island Sound and the Atlantic Ocean, with Block Island and Long Island to the west and Buzzards Bay and the Elizabeth Islands to the east. Approximately 90 miles outside the bay lies the edge of the Continental Shelf where the water drops from 600 feet in depth to 3,000 feet in about 12 miles.

3. Normal Tides. - Two high and two low tides occur each lunar day in the Narragansett Bay area with a mean high water of 1.45 feet, m.s.l., and mean low water of -1.45 feet, m.s.l., at Old Harbor, Block Island, a mean high water of 1.84 feet, m.s.l., and mean low water of -1.66 feet, m.s.l., at Newport Harbor and a mean high water of 2.47 feet, m.s.l. and mean low water of -2.13 feet, m.s.l. at Providence (Fox Point). Spring tides, which have a greater than average range, occur at the times of new moon and full moon when the tidal forces of the moon and the sun act in the same direction. Narragansett Bay produces a stationary wave type of tide, which causes high and low waters to occur almost simultaneously at all points within the bay, while the range of tide increases in a fairly uniform manner from south to north. Tidal data for Old Harbor, Block Island, Newport Harbor and Providence are summarized in Table 4-I.

TABLE 4-I

NORMAL TIDES
NARRAGANSETT BAY AREA

	Old Harbor, Block Island	Newport Harbor	Providence
Mean Tide Range (ft.)	2.9	3.5	4.6
Mean High Water (ft. above m.s.l.)	1.45	1.84	2.47
Mean Low Water (ft. below m.s.l.)	1.45	1.66	2.13
Average Spring Tide Range (ft.)	3.6	4.4	5.7
Predicted Maximum Spring Tide (ft. above m.s.l.)	3.0	3.3	4.0
Recorded Minimum Low Water (ft. below m.s.l.)	(1)4.0	4.3	5.1

(1) Estimated

Tidal data are given for 18 locations in the Narragansett Bay area in the yearly tide table publication of the U. S. Department of Commerce, Coast and Geodetic Survey, entitled "Tide Tables, East Coast, North and South America."

4. Recording Tide Gages in the Narragansett Bay Area. - Recording tide gages are presently in operation at 11 locations in the Narragansett Bay area. These locations are given on Plate No. 4-1. The gage identification numbers, as indicated on this plate, correspond to the item numbers as given in the following Table (4-II).

5. Factors Influencing Tides. - The normal predicted tides in Narragansett Bay are subject to numerous meteorological influences such as changes in atmospheric pressure and strong winds, besides the normal gravitational effects of the sun and the moon. On the North Atlantic coast, it is generally assumed that a drop in barometric pressure of one inch (of mercury) will cause about a one-foot rise in water levels. Normal winds within the bay have little effect on the tide levels, but do have noticeable influence on currents and timing. However, during coastal storms tide levels often build up several feet above the predicted elevations. When a severe storm occurs with strong southerly winds, the observed tide far exceeds predicted elevations.

C. EXPERIENCED HURRICANE TIDAL FLOODING

6. Recent Hurricanes. - In the last 21 years the Narragansett Bay area has been subjected to tidal flooding from three major hurricanes - severe flooding from those of September 1938 and August 1954 (Carol) - and moderate flooding from the hurricane of September 1944. These first two mentioned hurricanes followed a path from 30 to 80 miles west of Narragansett Bay

TABLE 4-II

TIDE GAGE INVENTORY DATA
NARRAGANSETT BAY AREA

Identification No.	Location	Type of Gage (1)	Period of Record	Agency
1.	Block Island, R.I. (Old Harbor, Ballards Inn)	A,B,C	Nov. 16, 1955 - To date	NED
2.	Newport, R.I. (Castle Hill Life Boat Station)	A,B,C	Oct. 10, 1955 - To date	NED
3.	Little Compton, R.I. (Sakonnet, Holder Wilcox Dock)	A,B,C	Sept. 27, 1956 - To date	NED
4.	North Kingstown, R.I. (Saunderstown) (Narragansett Marine Laboratory)	A,B,C	Oct. 10, 1955 - To date	NED
5.	Newport, R.I. (Coasters Harbor Island) (Constellation Dock)	A,B	Sept. 10, 1930 - To date	USC&GS
6.	North Kingstown, R.I. (Quonset Point Naval Air Station)	A,B,C	Dec. 17, 1956 - To date	NED
7.	Portsmouth, R.I. (Weyerhaeuser Timber Co.)	A,B,C	Oct. 24, 1955 - To date	NED
8.	Somerset, Mass. (Montaup Electric Co. Dock)	A,B,C	Aug. 24, 1956 - To date	NED
9.	Cranston, R.I. (Edgewood Yacht Club)	A,B,C	Oct. 11, 1955 - To date	NED
10.	Providence, R. I. State Pier No. 1	A,B	June 3, 1938-June 23,1947 Aug. 1956 - To date	USC&GS
11.	Providence, R.I. (Narragansett Electric Co., Manchester Street Station Dock)	A,B	1956 - To date	Narragansett Elec. Co.

(1) Type of Gage: (A) Recorder; (B) Staff Gage; (C) Maximum Level Gage

thereby placing the bay in the sector where the strongest and most damaging winds and surges occur. The tracks of these three storms are shown on Plate No. 4-2. Minor flooding has also occurred as the result of numerous other hurricanes and severe storms in the past 50 years. Detailed descriptions of the three hurricanes are given in the following paragraphs.

7. <u>Hurricane of September 21, 1938.</u> - The damage caused by tidal flooding from this hurricane was the highest ever experienced in the Narragansett Bay area. A significant factor was that the peak of the wind-induced tidal surge arrived at approximately the time of the predicted high tide. At Newport Harbor, where the water attained a height of 10.8 feet above mean sea level, the hurricane tide occurred approximately three-quarters of an hour before the normal high tide, but at Providence it occurred at about the same time and reached an elevation of 15.7 feet, m.s.l. Pertinent data concerning tidal heights, wind velocities and barometric pressures are included in Table 4-III.

The winds accompanying the hurricane of September 1938 were generally in excess of 75 m.p.h. in the Narragansett Bay area. At Block Island, the wind attained a maximum recorded 5-minute sustained velocity of 82 m.p.h. from the southeast and maximum gusts of 91 m.p.h. before the anemometer was blown down. A maximum 5-minute velocity of 87 m.p.h. from the southwest and gusts of 125 m.p.h. occurred at Providence. Minimum barometric pressures of 28.66 and 28.90 inches, respectively, were recorded at Block Island and Providence. The forward speed of the hurricane near Narragansett Bay was about 55 knots (63 m.p.h.). Tide curves showing the predicted and estimated tidal elevations at Newport and Providence are included as Plate No. 4-3. Hurricane flood levels based on observed high water marks along the east shore of Narragansett Bay are shown on Plate No. 4-6. The high water profile for the west shore of Narragansett Bay is similar to the east shore, as indicated by office records.

8. <u>Hurricane of September 14, 1944.</u> - The peak of the wind-induced tidal surge of this hurricane arrived shortly before the time of the predicted low tide and therefore caused only moderately high stages. The water reached an elevation of 3.6 feet above m.s.l. at Block Island, 6.6 feet above m.s.l. at Newport Harbor, and 9.9 feet above m.s.l. at Providence. These elevations were 4.0 feet, 7.6 feet, and 11.4 feet, respectively, above the predicted tidal heights (see Table 4-III for further data).

Wind velocities in Narragansett Bay during this hurricane were somewhat less than in the September 1938 storm. A one-minute sustained velocity of 88 m.p.h. from the southeast was recorded at Block Island and of 49 m.p.h. from the southeast at Hillsgrove, Rhode Island. Maximum gusts in excess of 100 m.p.h. were experienced at Block Island and 90 m.p.h. at Hillsgrove. The forward speed of the hurricane near Narragansett Bay was about 30 knots (34 m.p.h.). The predicted and experienced tide curves at Newport and Providence are shown on Plate No. 4-4.

9. Hurricane of August 31, 1954 (Carol). - This hurricane caused tidal flood levels in the Narragansett Bay area about one foot below the September 1938 flood levels. However, if the tidal surge had arrived at the same time as the predicted high tide, instead of 2 hours later, the maximum high water would have been about 0.4 foot higher at Providence than in 1938. The hurricane tide reached an elevation of 8.2 feet above m.s.l. at Block Island, 9.8 feet above m.s.l. at Newport Harbor, and 14.7 feet above m.s.l. at Providence. These elevations were 6.3 feet, 8.1 feet, and 13.1 feet, respectively, above the predicted tidal heights (see Table 4-III for further data).

The wind attained a maximum one-minute sustained velocity of 98 miles per hour from the southeast, with maximum gusts of 135 miles per hour at Block Island. A maximum one-minute sustained wind velocity of 90 miles per hour from the east-southeast, with maximum gusts of 105 miles per hour, occurred at Hillsgrove, Rhode Island. Minimum barometric pressures of 28.50 inches were recorded at Block Island and 28.79 inches at Providence. The forward speed of the hurricane close to Narragansett Bay was about 40 knots. Tide curves at Newport and Providence are shown on Plate No. 4-5. Hurricane flood levels are shown on Plate No. 4-6 for the same areas as for the September 1938 hurricane (see paragraph 7).

10. Frequency of Tidal Flooding. - Although hurricane tidal flooding has been recorded since 1635 in the Narragansett Bay area, records of elevations are meager until recent years. A flood frequency relationship has been approximated by combining elevations of the great floods of 1938 and 1954 and records of great historical storms with the records of the U. S. Coast and Geodetic Survey gages for the last 26 years.

Table 4-IV gives a chronological list of hurricanes and severe storms that caused tidal flooding or high tides in the Narragansett Bay area, with available data on the maximum tidal elevation at Providence. Information on these hurricanes and severe storms was obtained by a historical search. Table 4-V shows the tidal flood elevations rearranged in order of magnitude with calculated plotting positions in percent chance of occurrence in any one year based on three periods; (1) the period from 1931 to 1956 (26 years) for which records are available at Newport or Providence; (2) the period from 1815 to 1956 (142 years) to include newspaper accounts of great floods; and (3) the 322-year period between 1635 and 1956 for the purpose of plotting the approximate elevations of the 1635 and 1638 floods. A tidal flood elevation-frequency curve for Providence is given on Plate No. 4-7.

TABLE 4-III

PERTINENT DATA ON RECENT HURRICANES
NARRAGANSETT BAY AREA

Location	Tidal Flood Crest Time (E.S.T.)	Tidal Flood Crest Elev. (m.s.l.)	Predicted Tide Elev. (m.s.l.)	Max. Surge above Pred. Tide (feet)	Predicted Normal Tide: High Tide Time (E.S.T.)	Predicted Normal Tide: High Tide Elev. (m.s.l.)	Predicted Normal Tide: Low Tide Time (E.S.T.)	Predicted Normal Tide: Low Tide Elev. (m.s.l.)	Maximum Wind Velocity: 1 Min. Sustained Time (E.S.T.)	Maximum Wind Velocity: 1 Min. Sustained Vel. (m.p.h.)	Maximum Wind Velocity: Gust Vel. (m.p.h.)	Minimum Barometric Pressure Time (E.S.T.)	Minimum Barometric Pressure Pressure (inches)
Hurricane of Sept. 21, 1938													
Block Island, R. I. (5)	3:30 PM	9.3	1.3	8.0	5:32 PM	2.1	11:05 AM	-1.8	2:58 PM	82(1)	91	3:05 PM	28.66
Newport Harbor, R.I.	4:45 PM	10.8	2.4	8.4	5:32 PM	2.5	11:05 AM	-2.0	--	93(2)	--	3:40 PM	28.93
Providence, R.I.	5:25 PM	15.7	3.1	12.6	5:42 PM	3.2	11:15 AM	-2.4	4:07 PM	95	125(2)	3:45 PM	28.90
Hurricane of Sept. 14, 1944													
Block Island, R.I. (5)	10:00 PM(2)	3.6(2)	-0.4	4.0	5:46 PM	1.6	11:40 AM	-1.1	9:31 PM	88	100+	10:09 PM	28.34
Newport Harbor, R.I.	11:00 PM	6.6	-1.0	7.6	5:46 PM	2.0	11:40 AM	-1.3	--	70(2)	100(2)	11:00 PM	28.70
Providence, R.I.	11:25 PM	9.9	-1.5	11.4	5:56 PM	2.7	11:50 AM	-1.7	10:04 PM(3)	49(3)	90(3)	11:15 PM	28.51
Hurricane of Aug. 31, 1954													
Block Island, R.I. (5)	9:27 AM	8.2	1.9	6.3	9:17 AM	1.9	2:58 PM	-1.3	10:05 AM	98	135	10:00 AM	28.50
Newport Harbor, R.I.	10:45 AM	9.8	1.7	8.1	9:17 AM	2.3	2:58 PM	-1.5	--	--	--	10:15 AM(4)	28.72(4)
Providence, R.I.	11:30 AM	14.7	1.6	13.1	9:27 AM	3.0	3:08 PM	-1.9	10:30 AM(3)	90(3)	105(3)	11:12 AM	28.79

(1) Maximum 5-minute sustained wind velocity
(2) Estimated
(3) At Hillsgrove, R. I.
(4) At Newport Air Park, Middletown, R. I.
(5) At Old Harbor

TABLE 4-IV

HURRICANES AND SEVERE STORMS
NARRAGANSETT BAY AREA
(1635 to 1956)

Hurricane	Severe Storm	Maximum Tidal Elevation at Providence, R.I. — Feet above m.s.l.	Original Record
Aug. 15, 1635		17±	"14 ft. higher than ordinary"
Aug. 3, 1638		18±	"14 or 15 ft. above ordinary spring tide."
	Feb. 24, 1723		"Highest tide in 19 years"
Oct. 30, 1723			
	Jan. 22, 1751		
1757			
Oct. 24, 1761			
Oct. 19-20, 1770			
Aug. 1773			
	Aug. 12, 1778		
Aug. 19, 1788			
Sept. 9, 1804			
Oct. 9-10, 1804			
Sept. 23, 1815		14.2	"11.8 ft. above mean high tide"
Sept. 3, 1821			
Sept. 25, 1821			
July 24, 1829			
Oct. 3, 1841			
Sept. 10-11, 1854			
Oct. 30, 1866		8±	"Water flowed into West Water and Dyer Streets"
	Feb. 8, 1869		
Sept. 8, 1869		8.6	"6.2 ft. above mean high water"
Oct. 4-5, 1877			
Oct. 23, 1878		7±	
Dec. 10, 1878		7+	"Water washed over the Dorrance St. Wharf"

TABLE 4-IV (continued)

Hurricane	Severe Storm	Maximum Tidal Elevation at Providence, R.I.	
		Feet above m.s.l.	Original Record
	July 16, 1879		
Aug. 16-20, 1879			
	Feb. 11, 1886		
	July 12, 1888		
Sept. 10, 1889		7±	"Unusually high tide"
	Aug. 20, 1893		
Aug. 24, 1893			
Aug. 29, 1893		5.4	"Tide 3 ft. above mean high water"
	Feb. 7-8, 1895		
Sept. 9-10, 1896			
June 17, 1902			
June 29, 1902			
Sept. 16, 1902			
Sept. 16, 1903			
Sept. 15, 1904			
Nov. 9-14, 1904			
Aug. 30, 1911			
Sept. 16, 1912			
July 21, 1916			
Oct. 1, 1920			
Aug. 26, 1924			
Oct. 3, 1929			
	Nov. 30, 1932	Est. 6.4	
	Jan. 27, 1933	Est. 7.1	
	Oct. 1, 1936	Est. 6.6	
Sept. 21, 1938		15.7	
	Mar. 3, 1942	6.4	
	Mar. 1943	5.5	
Sept. 14, 1944		9.9	
	Nov. 30, 1944	6.2	
	Nov. 22, 1945	6.1	
	Mar. 3, 1947	5.7	
	Oct. 31, 1947	Est. 6.8	
	Nov. 12, 1947	Est. 7.3	

TABLE 4-IV (continued)

Hurricane	Severe Storm	Maximum Tidal Elevation at Providence, R.I.	
		Feet above m.s.l.	Original Record
Aug. 29, 1949		Est. 6.2	
	Oct. 22, 1949	Est. 6.8	
Sept. 11, 1950		Est. 6.4	
	Nov. 25, 1950	6.8	
	Dec. 8, 1950	6.2	
	Feb. 7, 1951	Est. 7.2	
	Nov. 3, 1951	Est. 7.0	
	Feb. 15, 1953	Est. 6.9	
	Apr. 13, 1953	Est. 6.6	
"Barbara" Aug. 15, 1953		Est. 5.5	
	Oct. 23, 1953	Est. 6.8	
	Nov. 7, 1953	Est. 7.9	
"Carol" Aug. 31, 1954		14.7	
"Edna" Sept. 11, 1954		5.5	
"Hazel" Oct. 15, 1954		5.9	

TABLE 4-V

TIDAL ELEVATIONS VS FREQUENCY
HURRICANES AND SEVERE STORMS

PROVIDENCE, RHODE ISLAND

Hurricane or Storm	Maximum Tidal Elevation at Providence, Rhode Island (ft., m.s.l.)	Percent Chance of Occurrence in any One Year (1) (1635-1956)	(1815-1956)	(1931-1956)
Hurricane, 3 August 1638	18+ (2)	0.16		
Hurricane, 15 August 1635	17+ (2)	0.47		
Hurricane, 21 September 1938	15.7 (3)		0.35	1.9
Hurricane, 31 August 1954	14.7 (3)		1.06	5.8
Hurricane, 23 September 1815	14.2 (3)		1.76	
Hurricane, 14 September 1944	9.9 (3)			9.6
Storm, 7 November 1953	7.9 (4)			13.5
Storm, 12 November 1947	7.3 (5)			17.3
Storm, 7 February 1951	7.2 (5)			21.2
Storm, 27 January 1933	7.1 (5)			25.0
Storm, 3 November 1951	7.0 (5)			28.8
Storm, 15 February 1953	6.9 (5)			32.7
Storm, 31 October 1947	6.8 (5)			36.5
Storm, 22 October 1949	6.8 (5)			40.4
Storm, 25 November 1950	6.8 (6)			44.2
Storm, 23 October 1953	6.8 (5)			48.1
Storm, 1 October 1936	6.6 (5)			51.9
Storm, 13 April 1953	6.6 (5)			55.8
Storm, 30 November 1932	6.4 (5)			59.6
Storm, 3 March 1942	6.4 (7)			63.5
Hurricane, 11 September 1950	6.4 (5)			67.3
Storm, 30 November 1944	6.2 (7)			71.2
Hurricane, 29 August 1949	6.2 (5)			75.0
Storm, 8 December 1950	6.2 (6)			78.8
Storm, 22 November 1945	6.1 (7)			82.7
Hurricane, 15 October 1954	5.9 (6)			86.5
Storm, 3 March 1947	5.7 (7)			90.4
Storm, March 1943	5.5 (7)			94.2
Hurricane, 15 August 1953	5.5 (5)			98.1
Hurricane, 11 September 1954	5.5 (6)			100.0

(1) Calculated plotting position: -

$$P = \frac{100\,(M-0.5)}{Y} \quad \text{where}$$

P= percent chance of occurrence in any one year.
M= number of the event.
Y= number of years of record.

(continued)

TABLE 4-V (continued)

(2) Estimated from historical account.

(3) Based on high water mark elevations at Providence, Rhode Island.

(4) Estimated by U.S. Coast and Geodetic Survey and stage related from Newport Harbor, Rhode Island

(5) Based on record of U.S. Coast and Geodetic Survey recording tide gage, located at Constellation Dock, Coasters Harbor Island, Newport, Rhode Island from September 10, 1930 to date, and stage related to Providence, Rhode Island.

(6) Based on reading of staff gage located at South Street Station Dock, Narragansett Electric Company, Providence, Rhode Island.

(7) Based on record of U. S. Coast and Geodetic Survey recording tide gage, located at State Pier No. 1, Providence, Rhode Island from June 3, 1938 to June 23, 1947

D. DESIGN HURRICANE TIDAL FLOOD

11. Design Storm. - The design storm used in determining the required height of protective structures has been established with the assistance of the U. S. Weather Bureau and the Beach Erosion Board, aided by the Texas A&M Research Foundation. The design storm, equivalent to the Standard Project Hurricane (SPH), was based on the transposed Cape Hatteras hurricane of September 1944, which is the largest Atlantic Coast hurricane of record, and was adjusted according to SPH indices by the U. S. Weather Bureau. The SPH criteria were established by enveloping observed hurricane parameters such as central pressure and radius of maximum winds separately and smoothing geographically. In deriving the SPH, the 1944 storm was transposed so that it would be over water between Cape Hatteras and the New England coast, resulting in a central pressure index of 27.71 inches near the mouth of Narragansett Bay. This CPI has approximately 0.5 inch lower barometric pressure than actually occurred in September 1944. The center of the transposed hurricane was assumed to move along the critical storm track with various forward speeds.

12. Wind Fields. - Wind field charts of the transposed September 1944 storm adjusted by SPH indices were prepared by the Hydrometeorological Section (HMS) of the U. S. Weather Bureau for various rates of forward speed of 10, 20, 30, 40, 50 and 60 knots, and with different radii to maximum winds. Two sets of charts were prepared for each of the above conditions; one set shows the hurricane at hourly intervals over the open ocean, and the second indicates the wind speeds at corresponding times in Narragansett Bay. In general, the faster moving storms, that is, 40 knots and greater, produce higher wind velocities off-shore and in Narragansett Bay. The 50 and 60 knot storms do not produce wind velocities much higher than the 40 knot because such high forward speed has the effect of pinching off the warm, moist air advection from the south and east and therefore leads to some filling of the storm. Although 50 or 60 knot storms can produce the highest wind velocities, the storm is traveling so fast that it tends to run ahead of the tidal surge. This tendency would have a much lesser effect on building up the surge than with the 40 knot storm. The 40 knot storm, with large radii of maximum winds, was therefore selected as a basis for the critical conditions and calculation of the surge heights at the mouth of Narragansett Bay and at the Fox Point Hurricane Barrier.

An average maximum wind velocity of 90 miles per hour from the SSE was determined for the area from the entrance of the bay to Providence for the 40 and 50 knot storms, as shown in U. S. Weather Bureau Memoranda HUR 7-55 dated 21 January 1959 entitled, "Transposed Hurricane for Lower Narragansett Bay Barrier Studies", and HUR 7-66 dated 11 December 1959 entitled, "Transposed September SPH Isovel Charts for Forward Speed of 50 Knots."

A comparison of the wind patterns for a standard project hurricane having 30 and 60 knot forward speeds is given in U. S. Weather Bureau Memorandum HUR 7-66a, dated 21 December 1959 entitled, "A Comparison of Isovel Patterns for September 1944 Hurricane Moving at 30 and 60 Knots."

The results showed that the overall wind pattern at 60 knot forward speed as compared to the wind pattern when moving at 30 knots extended over a slightly larger area with only a small increase in wind velocity.

Wind field data for the design 40 knot storm are shown on isovel charts and tabulations given in HUR 7-55. Typical isovel charts of the 40 knot storm indicating the maximum wind fields near the mouth and in Narragansett Bay are shown on Plate Nos. 4-8 and 4-9. Corresponding isovel charts of the September 1938 hurricane are shown on Plate Nos. 4-10 and 4-11. The 90 miles per hour winds of the 40 knot storm are about 50 percent greater than the maximum bay winds of the 1938 hurricane.

13. Storm Surge at Mouth of Bay. -

a. General. Analytical computations of the storm surge variations at the mouth of Narragansett Bay for the SPH have been carried out for the 10, 20, 30 and 40 knot storm speeds. The September 1938 storm surge was used as a basis for analytical studies by Texas A&M Research Foundation. The wind fields for the 1938 storm and the transposed 1944 storm furnished by the U. S. Weather Bureau were used to determine the wind stresses over ocean waters and the resulting forced surge over the continental shelf. A description of the method and calculations used are contained in Beach Erosion Board Technical Memorandum No. 83, "Approximate Response of Water Level on a Sloping Shelf to a Wind Fetch which moves towards Shore," dated June 1956, by Dr. R. O. Reid (Texas A&M).

b. September 1938. The forward speed of this hurricane was computed to be about 42 knots from Cape Hatteras to the mouth of Narragansett Bay by Texas A&M Research Foundation. The path of the center of the hurricane was about 80 miles west of Narragansett Bay thus producing a wind field most critical at the mouth of the bay. The wind-induced tidal surge arrived about three-quarters of an hour before the normal high tide. With a coincident tide of 2.4 feet above m.s.l. at Newport Harbor, the maximum still-water elevation of 10.8 feet above m.s.l. gives a surge of 8.4 feet. Other data on this hurricane are shown in paragraph 7 and Table 4-III.

c. 40-Knot Storm. Using the September 1938 surge hydrograph as a control and considering a 40-knot storm speed and the basic wind field of HUR 7-55, a hydrograph was computed by Texas A&M Research Foundation. The computed surge hydrograph has about the same width and a response factor of 1.33 times the height of the 1938 surge, giving a surge height of 11.2 feet at Newport Harbor as shown on Plate No. 4-12.

d. 20-Knot Storm. In order to make certain that the 40 knot storm speed is critical a brief analysis of a 20 knot storm was made. Using the September 1938 surge hydrograph of 8.4 feet as a control, the basic wind field of the HUR 7-55 (for a storm moving 40 knots) a hydrograph was computed by Texas A&M Research Foundation. Response factors of 1.28 times the height and 1.54 times the width were obtained for the surge hydrograph, giving a surge of 10.8 feet at Newport Harbor. As the 40 knot storm is more critical for the Fox Point project no further studies were made.

14. Storm Surge in Narragansett Bay. - Having determined the level of the surge at the mouth of the bay the next step is to estimate the build-up in levels within the bay from the dynamic effect of the moving surge and from wind set-up. The September 1938 storm surge was used as a basis for estimating the rise in water levels within the bay.

a. Observed September 1938 Conditions.

Analysis of the 1938 hurricane data is as follows:

	Newport Harbor, R.I.	Providence, R.I.
1938 Hurricane Tide Peak, ft., m.s.l.	10.8	15.7
Coincident Predicted Normal Tide, ft., m.s.l.	2.4	3.1
Difference, or Storm surge, ft.	8.4	12.6
Build-up, Newport Harbor to Providence, ft., (difference in levels)	4.2	

The model tests, which were performed at the Waterways Experiment Station, indicated a dynamic build-up of 2.5 feet (surge heights at Newport Harbor, 8.2 feet, and Providence 10.7 feet) as compared with the total observed build-up of 4.2. The difference between the two was 1.7 feet of wind set-up within Narragansett Bay. The wind speed, taking one hour average prior to the peak still water level, was determined to be 54 miles per hour from the south.

b. 40-Knot Storm. The model test of the 40 knot storm indicated a dynamic build-up of 3.3 feet which resulted from the difference in surge heights of 11.0 feet at Newport Harbor and 14.3 feet at Providence. For the 40 knot storm, the average wind for one hour prior to the peak still water level was determined to be 70 miles per hour from the south. The wind set-up in the bay is approximately proportional to the square of the ratio of the average hourly wind velocity prior to the peak still water levels. This ratio of $(70/54)^2$ gives a factor of 1.68 applied to the September 1938 wind set-up of 1.7 feet at Newport Harbor. The calculated design wind set-up is 2.9 feet at Fox Point which produces a design surge of 17.4 feet.

15. Design Still Water Level. - The design surge of 17.4 feet at Fox Point was applied to a coincident predicted mean spring high water elevation of 3.1 feet above m.s.l., which produced a maximum peak still water level of 20.5 feet above m.s.l. (See Plate No. 4-13). The following tabulation gives a comparison of the calculated design surge

with the corresponding data for the hurricane of September 21, 1938.

	Design	Sept. 1938
Surge at Newport Harbor (feet)	11.2	8.4
Dynamic build-up in Bay (feet)	3.3	2.5
Wind set-up in Bay (feet)	2.9	1.7
Design surge at Fox Point (feet)	17.4	12.6
Coincident tide (ft., m.s.l.)	3.1	3.1
Maximum still water level (ft., m.s.l.)	20.5	15.7

The mean spring high water of 3.1 feet, m.s.l., taken coincident with the design surge, lies between a mean high water and a maximum spring high water; with a mean high water of 2.5 feet, m.s.l., the still water level would be 19.9 feet, m.s.l.; with a maximum spring high water of 4.0 feet, m.s.l., the still water level would be 21.4 feet, m.s.l. A maximum spring tide of 4.0 feet, m.s.l., is predicted, by the tide tables, to occur on an average of once every two years during the hurricane season (June - October, inclusive), so this is too rare an occurrence to combine with the design surge. A tidal elevation of 4.0 feet, m.s.l., or higher occurs on an average of about 15 hours per hurricane season or approximately 0.4 percent of time. A high tide of 3.1 feet, m.s.l., or higher is predicted, by the tide tables, to occur on an average of 13 times a month during the hurricane season. A recorded tidal elevation of 3.1 feet, m.s.l., or higher occurs on an average of about 176 hours per hurricane season, or approximately 5 percent of time.

The fact that high tidal elevations are recorded far more frequently than they are predicted is caused by sustained onshore winds not necessarily connected with any storm or hurricane and also by two meteorological conditions that are present during a hurricane but have not been analyzed separately in arriving at the design still water level. The first of these is the "forerunner" or "build-up" that may precede the actual arrival of a hurricane or storm by one or two days. This will be in the form of a sea swell causing the water surface to become irregularly higher. The other is the rise in water surface due to the lower atmospheric pressure near the center of the hurricane. This rise in water level is roughly equal to one foot for each inch of mercury drop.

16. Waves. - Significant wave height and period at Fox Point for the average maximum wind of 90 m.p.h. from SSE were furnished by the Beach Erosion Board staff. Using Bretschneider's Wave Step Method from the mouth of the bay to the Fox Point Hurricane Barrier resulted in a significant wave height of 6.5 feet with a period of 5.5 seconds at Fox Point Barrier.

The significant wave height, the average of the highest one-third of the waves in the trains, was used to determine the size of riprap, amount of overtopping and barrier top elevation. The maximum wave height is 1.58 times the significant height and has a one percent probability in the wave train. This wave was used to determine the height of runup and for the structural design of vertical walls and gates. Waves reaching heights equal to 0.78 of the still water depth will break and transform from oscillatory waves to waves of translation.

The average wind velocities in Narragansett Bay during the design hurricane were obtained from the isovel charts in the U. S. Weather Bureau's Memorandum HUR 7-55 dated 21 January 1959. The maximum average wind of 90 m.p.h. was assumed to occur about 1½-hour prior to the design peak still water level as did the 1938 and 1944 hurricanes. Averages of one-half hour time intervals of wind and water surface elevations were used to determine the average height of significant and maximum waves and periods. The significant and maximum wave heights for wind velocities other than maximum were assumed to vary as the square of the ratio of the wind velocities. The wave periods were determined by the relationship of $H_s/T^2 = 0.22$; where H_s is the significant wave height and T is the period. The average design wind velocities, wave heights and periods coincident with average still water levels for one-half hour time intervals are shown on Plate No. 4-14 and tabulated in following Table 4-VI.

TABLE 4-VI

DESIGN WIND VELOCITIES, WAVE HEIGHTS AND PERIODS

Time	Stillwater Level (ft.,msl)	Wind Velocity (m.p.h.)	H_s Significant Wave Height (feet)	$1.58H_s$ Maximum Wave Height (feet)	Period (secs.)
1:40-2:10	3.5	31	3.8	6.0	4.2
2:10-2:40	4.5	44	4.5	7.1	4.5
2:40-3:10	6.4	60	5.2	8.2	5.4
3:10-3:40	8.7	79	5.9	9.3	5.2
3:40-4:10	11.4	90	6.5	10.3	5.5
4:10-4:40	14.8	84	6.3	10.0	5.4
4:40-5:10	18.3	70	5.7	9.0	5.1
5:10-5:40	20.5	54	5.1	8.1	4.8
5:40-6:10	16.9	42	4.4	7.0	4.5
6:10-6:40	11.5	36	4.1	6.5	4.3
6:40-7:10	8.5	32	3.9	6.2	4.2
7:10-7:40	6.2	28	3.6	5.7	4.0

17. Top Elevation of Barrier. - The barrier was designed with a top elevation of 25.0 feet above m.s.l., which would be 4.5 feet above the maximum design still water level. This barrier height is designed to

prevent excessive overtopping from waves. The pumps required for fresh water run-off will also take care of water overtopping.

18. Wave Run-up and Overtopping. - The barrier consists of earth-fill dikes with oceanside riprap slopes of 1 on 1½ extending about 1,500 feet on the west side, 550 feet on the east side, and approximately 760 feet of vertical structures across the river. The top of the barrier is at elevation 25 feet, m.s.l., except the pumping station, which is 215 feet in length with a top elevation of 68 feet, m.s.l., and the river gates extending for 150 feet with a top elevation of 35 feet, m.s.l. Three gate structures will close off existing streets and an access road that are crossed by the barrier. A general layout plan of the Fox Point Barrier is shown on Plate No. 4-15. The amount of overtopping was calculated by a method derived by the Beach Erosion Board staff and was determined for each one-half hour time interval using the average significant wave height, period, and average still water level computed for their respective time intervals throughout the design surge period as shown on Plate No. 4-14.

Overtopping data were obtained by interpolation and extrapolation of the curves in the Beach Erosion Board Technical Memorandum No. 64 entitled, "Laboratory Data on Wave Run-up and Overtopping on Shore Structures." Since the wave heights in a wave train vary considerably from wave to wave, it was necessary to determine partial values of overtopping associated with each height in the wave spectrum. These values were then weighted according to the relative frequency of occurrence of the particular height and then summed for the final value of overtopping associated with a wave train of given significant height.

Wave run-up data were obtained from the Beach Erosion Board Technical Report No. 4, to determine the lower limit of wave height for which overtopping occurs. Waves that broke seaward of the structure, due to shallow depths, were assumed to reform into lower waves. These waves were redistributed throughout the rest of the height groups according to the proportion of the total number of waves in the group.

The amounts of overtopping at various areas behind the barrier for the maximum ½-hour time interval (design conditions) were as follows:

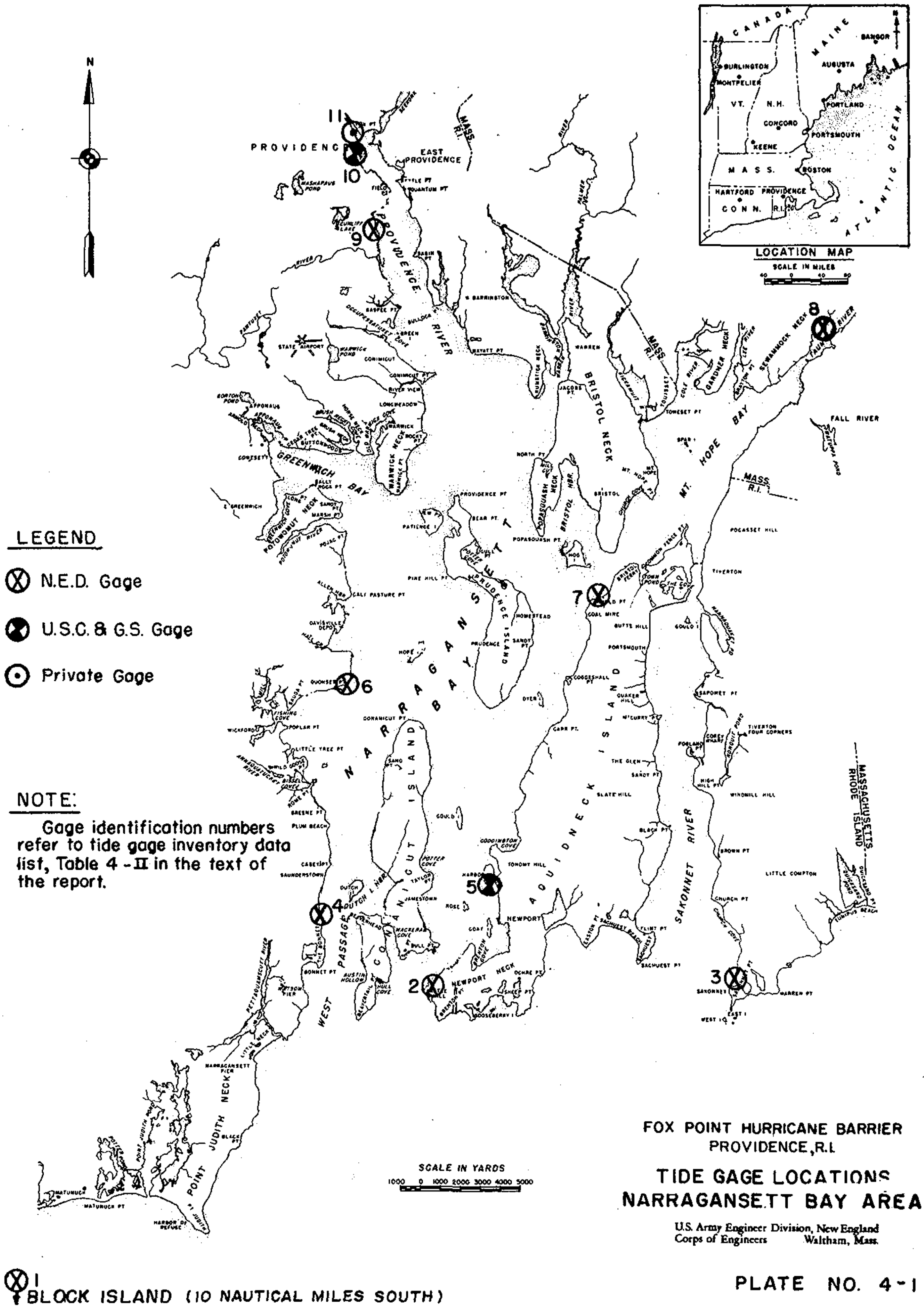
Area		Peak Q (c.f.s.)	Volume (Ac.-Ft.)
West Bank		190	7.9
East Bank		68	2.9
River		96	4.0
	Total	354	14.8

Therefore, during the one-half hour period of maximum overtopping, the discharge over the barrier would be .354 cubic feet per second resulting in a volume of 14.8 acre-feet. Overtopping during the design tide extends over a period of 2½-hours with a total volume of 21 acre-feet. A summary of the wave run-up and overtopping for the various points along the barrier is shown in Table 4-VII.

TABLE 4-VII
WAVE RUN-UP AND OVERTOPPING

Structure	Elevation Top (ft.,msl)	Elevation Ground at Toe (Ave.) (ft., msl)	Seaward Face	Length of Structure (ft.)	Max. Wave Height at Toe (1) (ft.)	Max. Run-up(1) Height (ft.)	Max. Run-up(1) Elevation (ft.,msl)	Overtopping Max. Rate(1) (c.f.s.)	Overtopping Volume(1) (Ac.-ft.)	Total Volume(2) (Ac.-ft.)
Dike (West of Allens Ave)	25	+18	1 on 1½ R.	170	2.0(3)	3.0	23.5	0	0	0
Allens Ave. Gate	25	+11	Vertical (Steel & Conc.)	70	7.4(3)	15.9	36.4	20.0	0.8	1.3
West Embankment	25	+11	1 on 1½ R.	1330	7.4(3)	5.9	26.4	165.0	6.9	6.9
Narragansett Elec. Co. Gate	25	+ 9	Vertical (Steel & Conc.)	15	8.1	10.5	31.0	5.0	0.2	0.4
West Abutment	25	-12	Vertical (Conc.)	55	8.1	10.5	31.0	17.0	0.7	1.4
Pumping Station	68	-20	"	215	8.1	10.5	31.0	0	0	0
Concrete Barrier (Service Bridge)	25	-22	"	180	8.1	10.5	31.0	57.0	2.4	4.8
River Gates	35	-17	Vertical (Steel & Conc.)	150	8.1	10.5	31.0	0	0	0
Concrete Barrier (Un-bridged)	25	-14	Vertical (Conc.)	70	8.1	10.5	31.0	22.0	0.9	1.9
	25	+ 8	Vertical (Conc.)	90	8.1	17.2	37.7	29.0	1.2	2.5
East Embankment	25	+12	1 on 1½ R.	250	6.6(3)	6.0	26.5	28.0	1.2	1.2
So. Main St. Gate	25	+14	Vertical (Steel & Conc.)	40	5.1(3)	11.8	32.3	11.0	0.5	0.6
East Embankment	25	+18	1 on 1½ R.	300	2.0(3)	3.0	23.5	0	0	0
							TOTALS	354.0	14.8	21.0

(1) Based on design stillwater level 20.5 ft., m.s.l. for ½-hour time interval. Higher waves occurring at lower stillwater levels of design tide are not critical.
(2) Based on duration of overtopping (2½-hours).
(3) Based on breaking wave height; $H_B = 0.78\ d$, where d = water depth at toe of structure.



LEGEND

N.E.D. Gage

U.S.C. & G.S. Gage

Private Gage

NOTE:

Gage identification numbers refer to tide gage inventory data list, Table 4 - II in the text of the report.

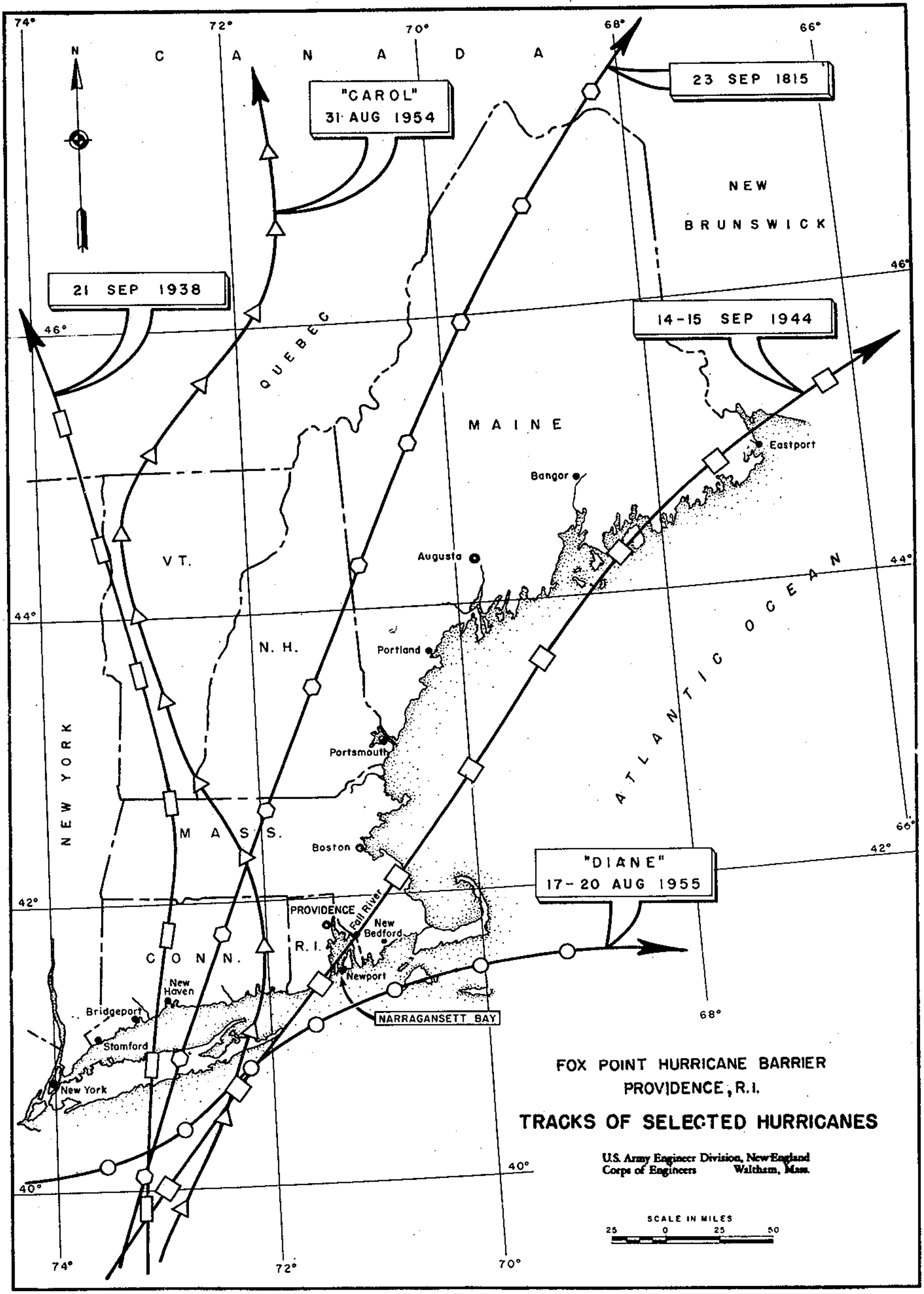
FOX POINT HURRICANE BARRIER
PROVIDENCE, R.I.

TIDE GAGE LOCATIONS
NARRAGANSETT BAY AREA

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

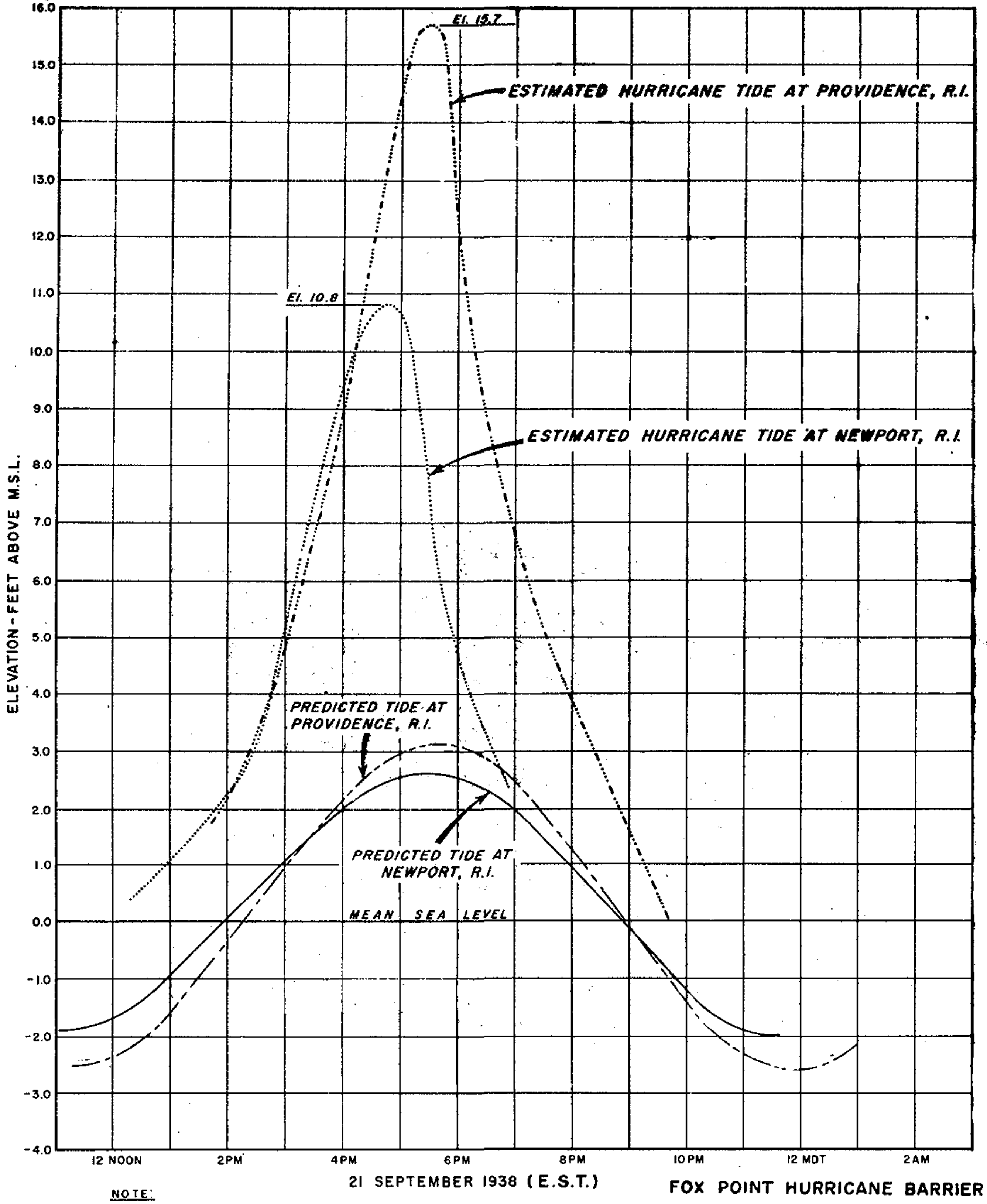
1
BLOCK ISLAND (10 NAUTICAL MILES SOUTH)

PLATE NO. 4-1



CANADA
QUEBEC
NEW BRUNSWICK
MAINE
VT.
N. H.
MASS.
CONN.
R. I.
NEW YORK
ATLANTIC OCEAN
"CAROL" 31 AUG 1954
23 SEP 1815
21 SEP 1938
14-15 SEP 1944
"DIANE" 17-20 AUG 1955
Eastport
Bangor
Augusta
Portland
Portsmouth
Boston
PROVIDENCE
Fall River
New Bedford
Newport
NARRAGANSETT BAY
New Haven
Bridgeport
Stamford
New York
74°
72°
70°
68°
66°
46°
44°
42°
40°
FOX POINT HURRICANE BARRIER
PROVIDENCE, R.I.
TRACKS OF SELECTED HURRICANES
U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.
SCALE IN MILES
25 0 25 50

PLATE NO. 4-2



NOTE:
Tide curves at Newport and Providence are based on observed high water elevations.

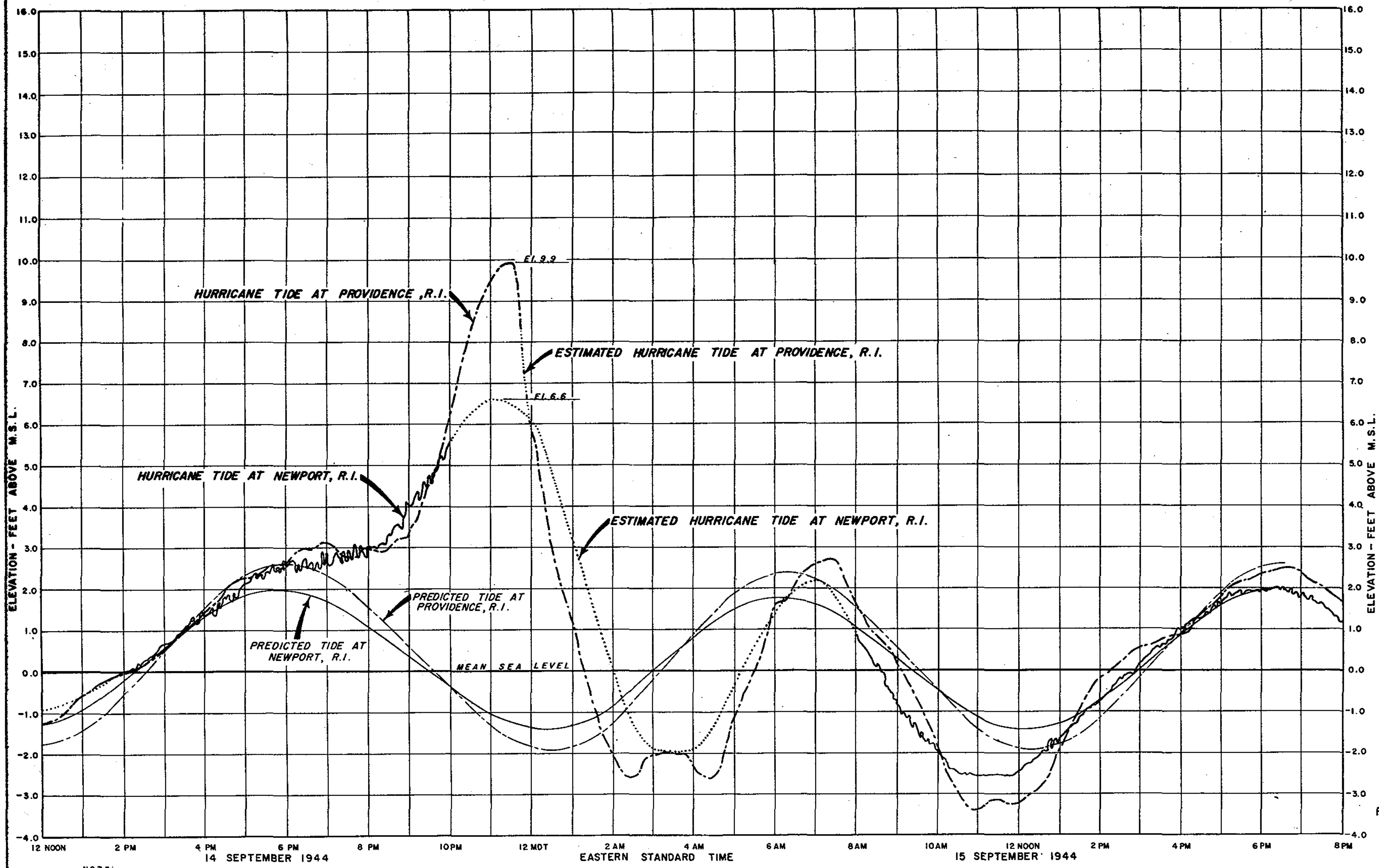
FOX POINT HURRICANE BARRIER
PROVIDENCE, R.I.

TIDE CURVES

HURRICANE OF 21 SEPTEMBER 1938

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

PLATE NO. 4-3



NOTE:

Tide curve at Newport is based on record of U.S.C.& G.S. recording gage at Coasters Harbor Island; at Providence, on record of U.S.C.& G.S. recording gage at State Pier No. 1 and on staff gage readings and high water elevations at South Street Station, Narragansett Electric Co.

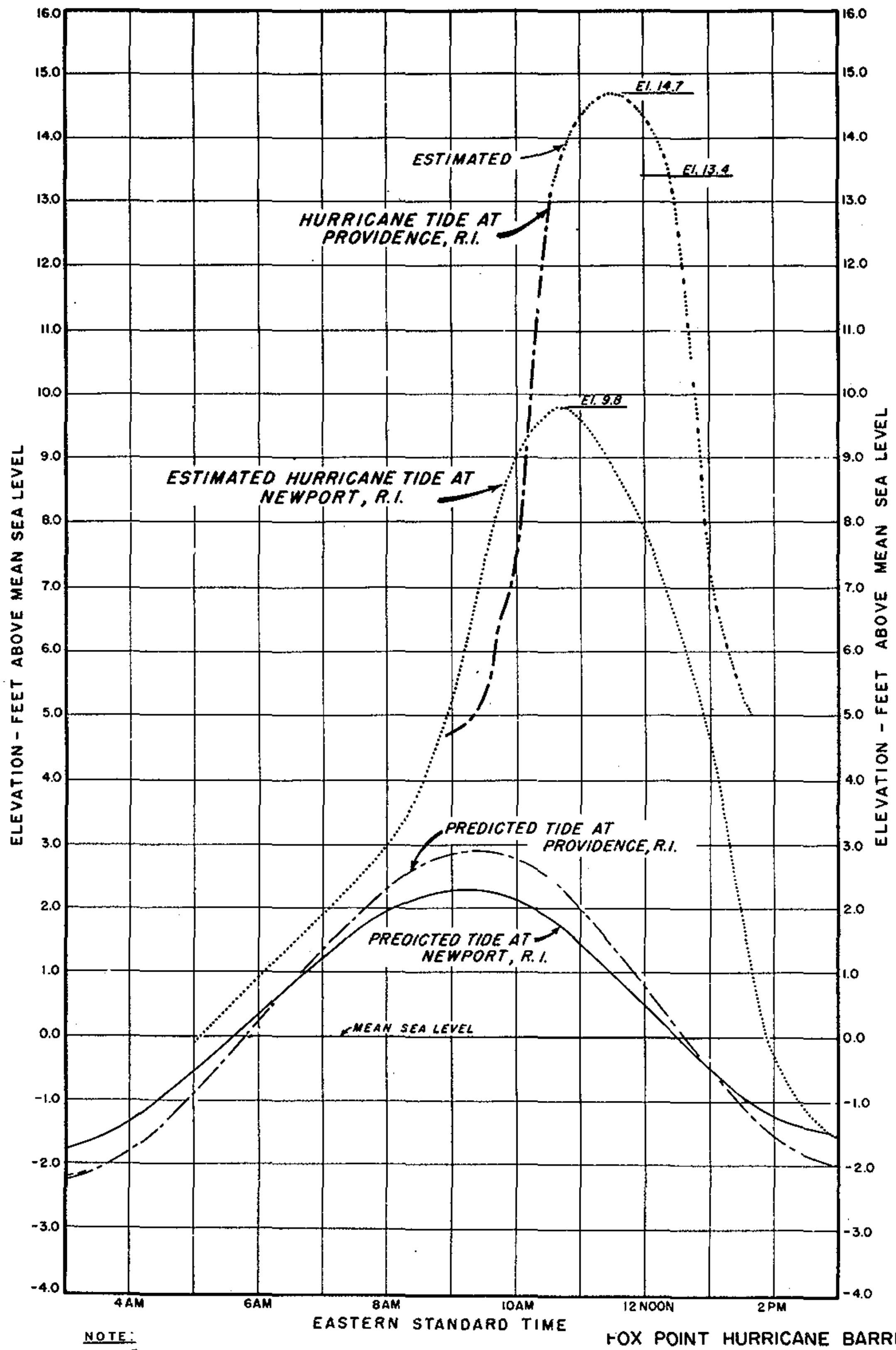
FOX POINT HURRICANE BARRIER
PROVIDENCE, R.I.

TIDE CURVES

HURRICANE OF 14-15 SEPTEMBER 1944

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

PLATE NO. 4-4

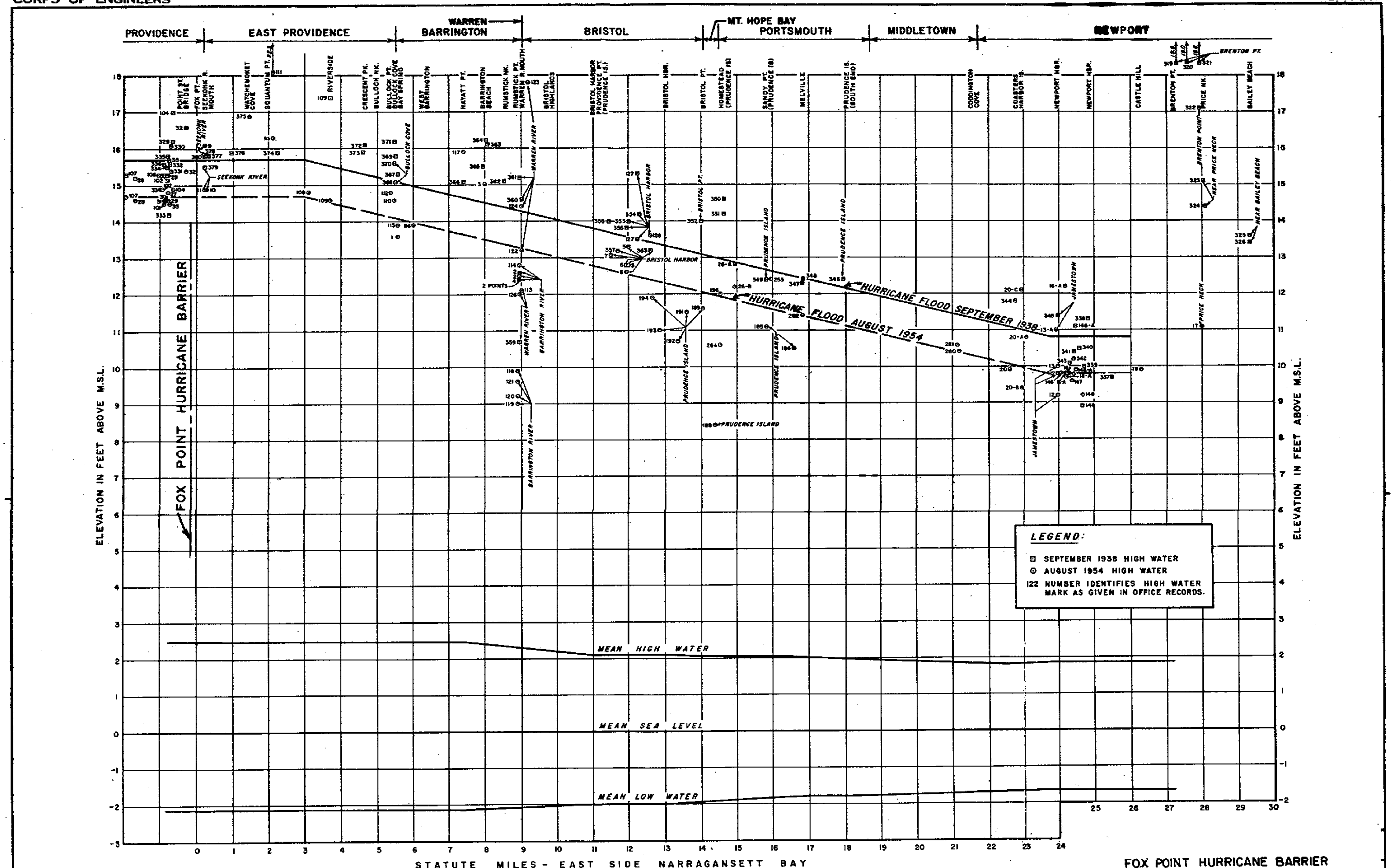


NOTE:
Tide curve at Newport is based on observed high water elevations. Tide curve at Providence is based on observed high water elevations and staff gage readings at South Street Station, Narragansett Electric Co.

FOX POINT HURRICANE BARRIER
PROVIDENCE, R.I.
TIDE CURVES
HURRICANE OF 31 AUGUST 1954

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

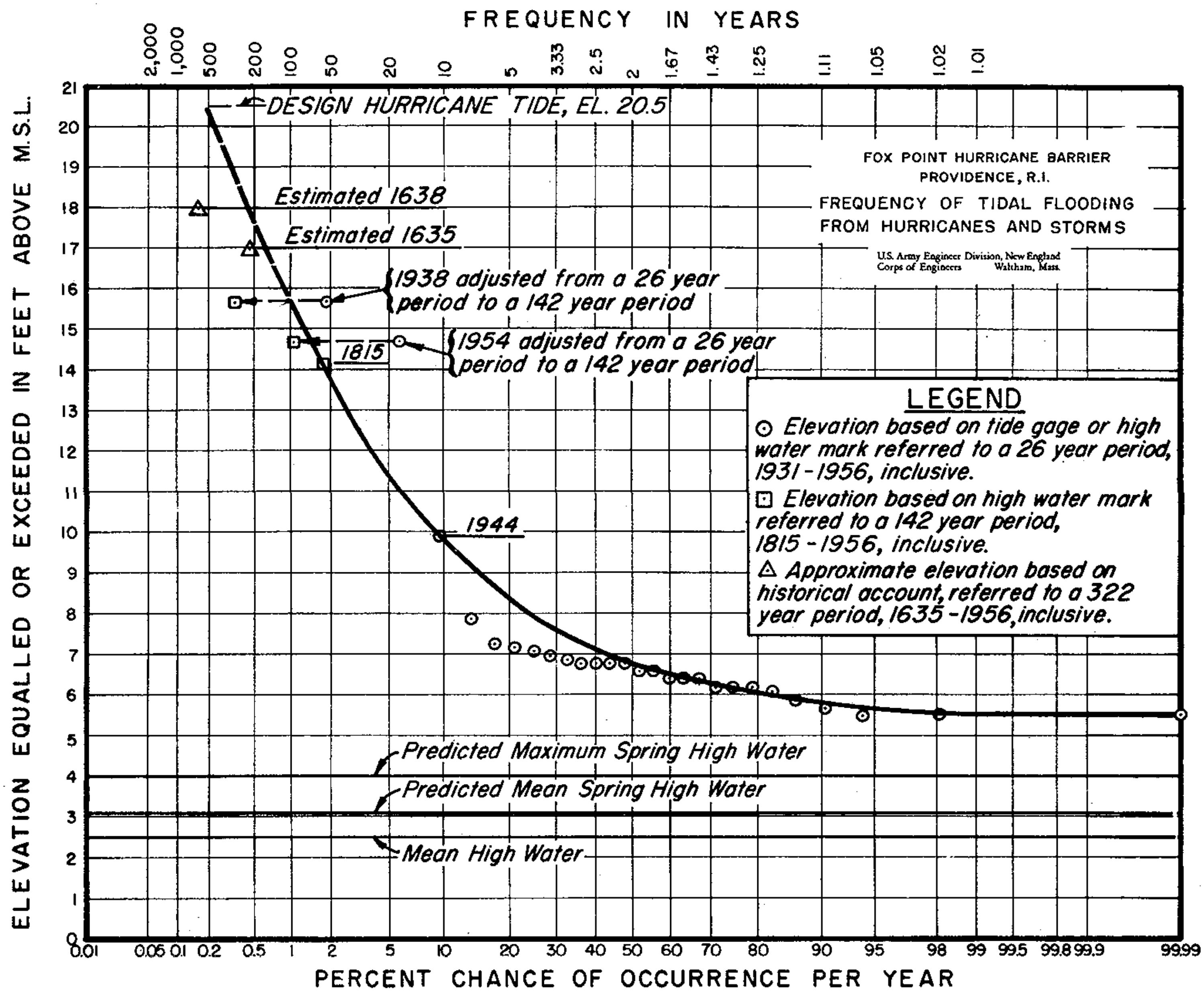
PLATE NO. 4-5



FOX POINT HURRICANE BARRIER
PROVIDENCE, R.I.

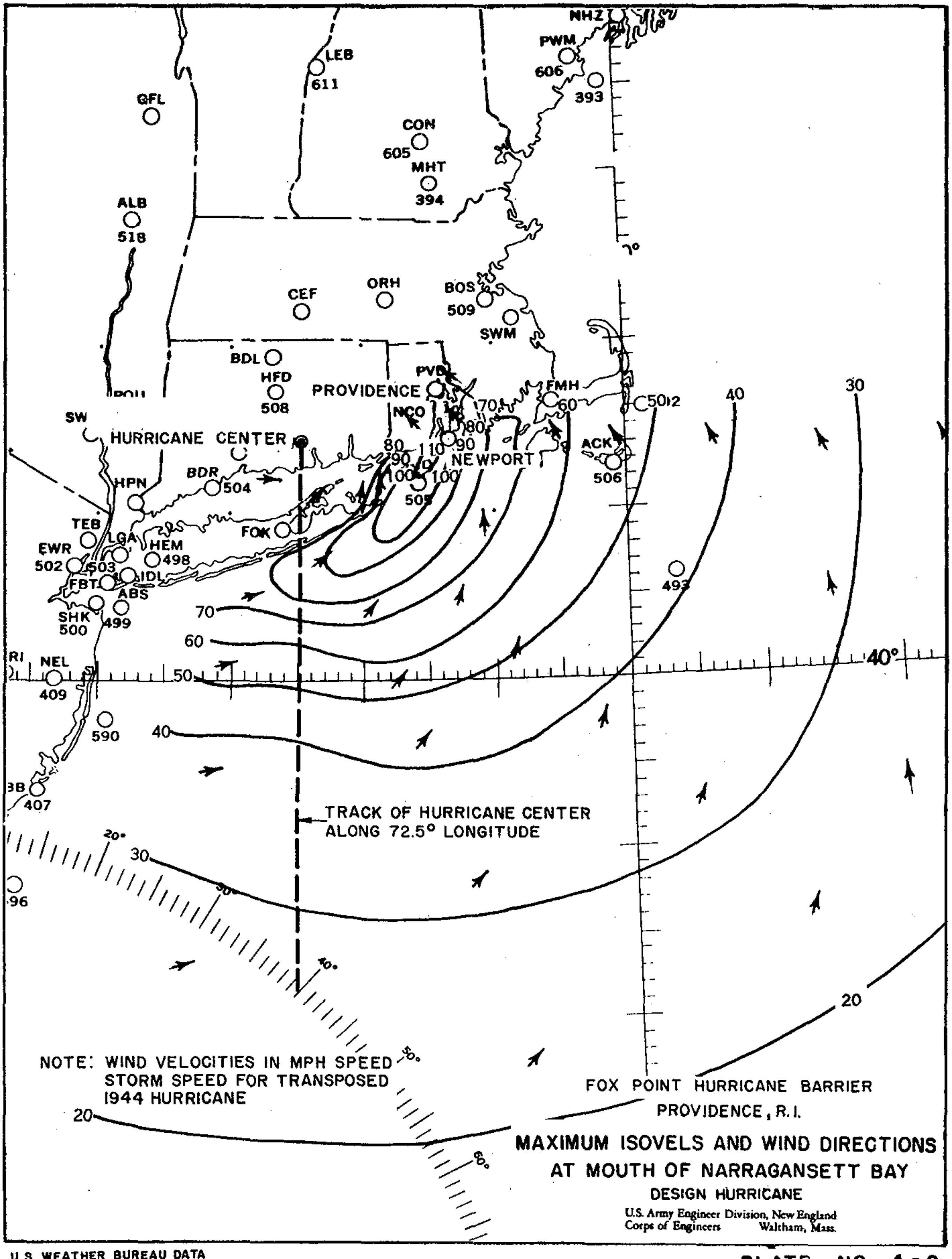
HURRICANE FLOOD LEVELS
EAST SHORE OF NARRAGANSETT BAY

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.



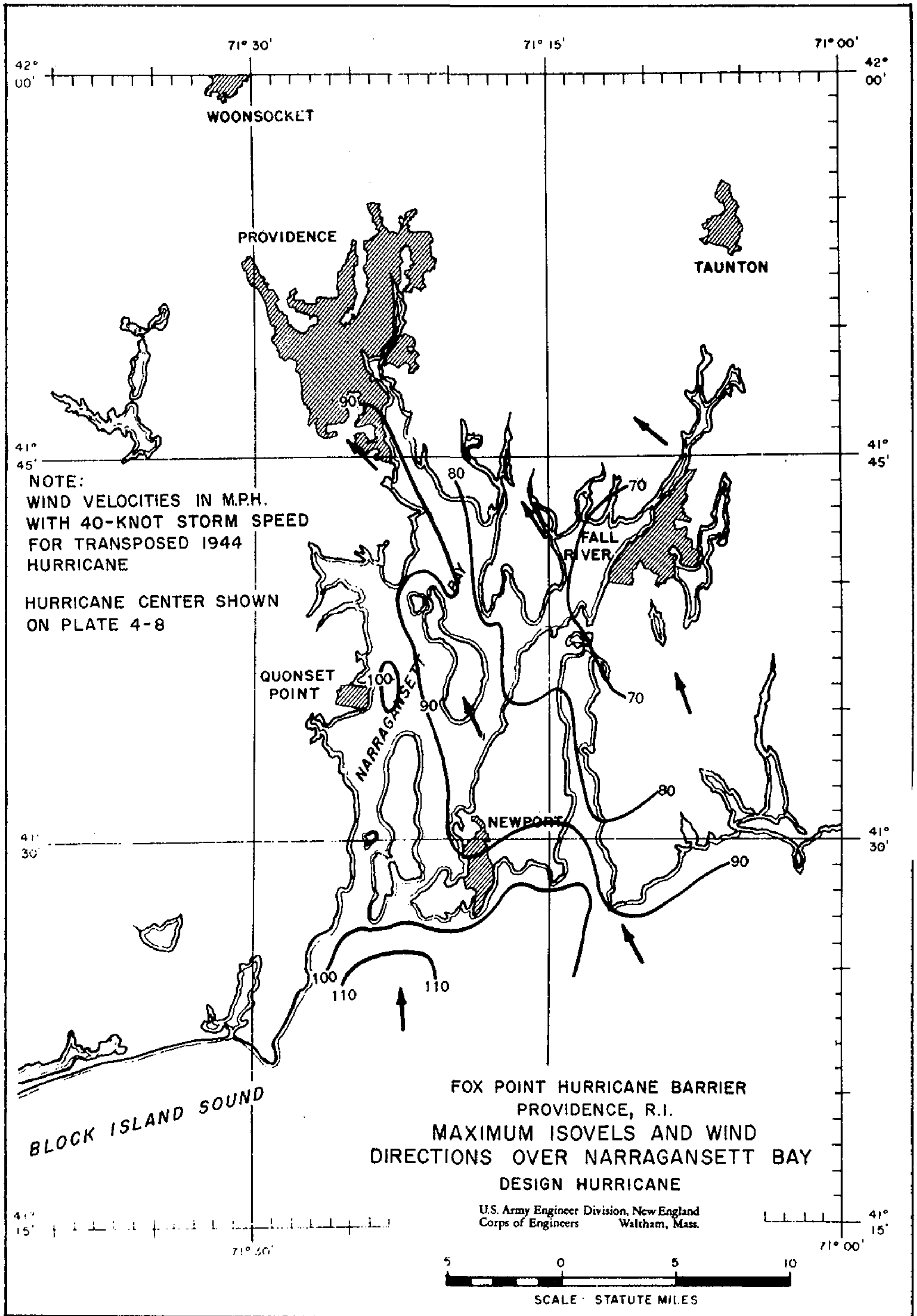
FREQUENCY IN YEARS
2,000 1,000 500 200 100 50 20 10 5 3.33 2.5 2 1.67 1.43 1.25 1.11 1.05 1.02 1.01
ELEVATION EQUALLED OR EXCEEDED IN FEET ABOVE M.S.L.
DESIGN HURRICANE TIDE, EL. 20.5
Estimated 1638
Estimated 1635
1938 adjusted from a 26 year period to a 142 year period
1815
1954 adjusted from a 26 year period to a 142 year period
1944
FOX POINT HURRICANE BARRIER
PROVIDENCE, R.I.
FREQUENCY OF TIDAL FLOODING FROM HURRICANES AND STORMS
U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.
LEGEND
⊙ Elevation based on tide gage or high water mark referred to a 26 year period, 1931-1956, inclusive.
⊡ Elevation based on high water mark referred to a 142 year period, 1815-1956, inclusive.
△ Approximate elevation based on historical account, referred to a 322 year period, 1635-1956, inclusive.
Predicted Maximum Spring High Water
Predicted Mean Spring High Water
Mean High Water
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
PERCENT CHANCE OF OCCURRENCE PER YEAR

PLATE NO. 4-7



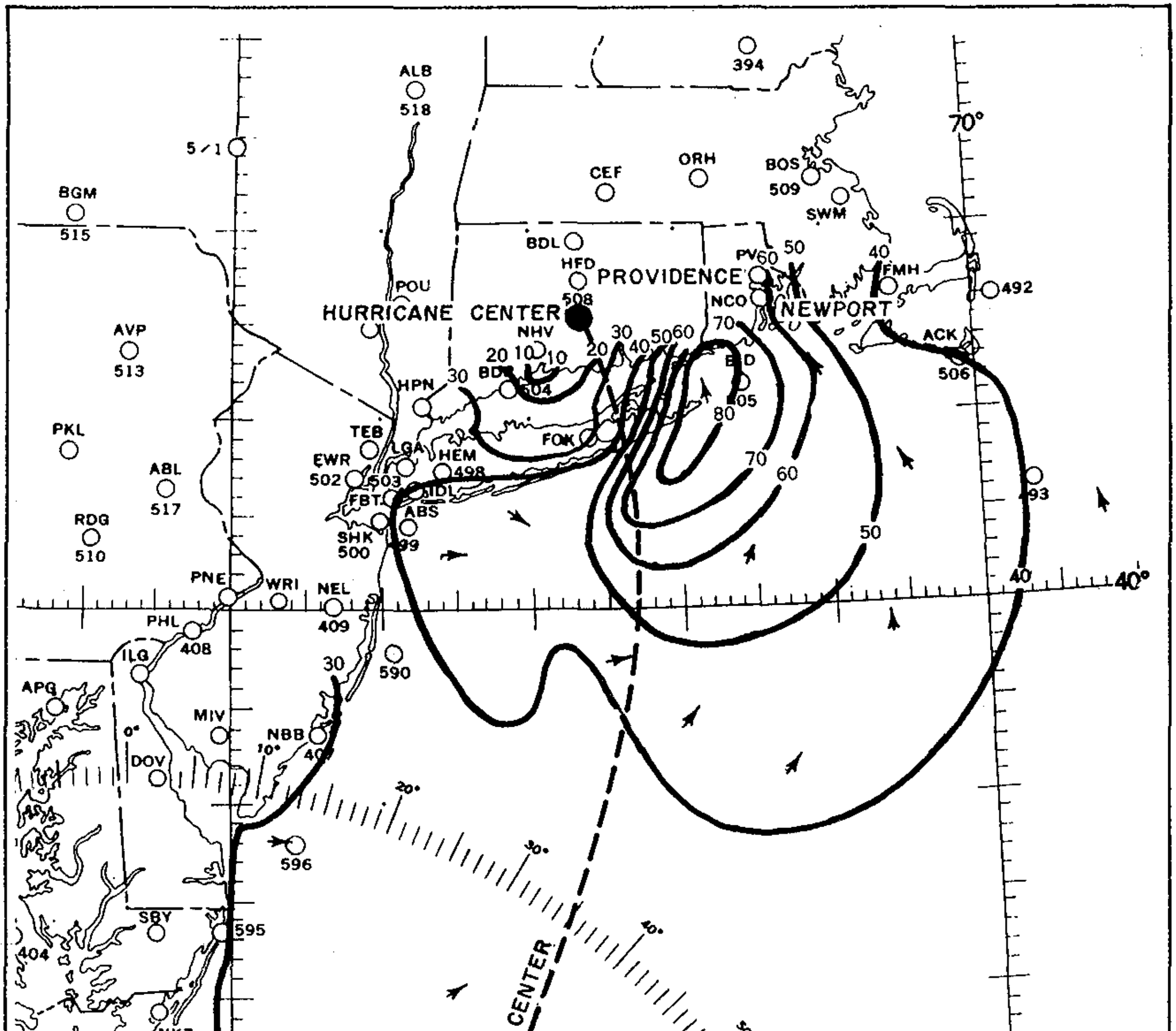
U.S. WEATHER BUREAU DATA

PLATE NO. 4-8



U.S. WEATHER BUREAU DATA

PLATE NO. 4-9



FOX POINT HURRICANE BARRIER
PROVIDENCE, R.I.

MAXIMUM ISOVELS AND WIND DIRECTIONS AT MOUTH OF NARRAGANSETT BAY

HURRICANE OF 21 SEPT. 1938, 1600 EST

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

NOTE: WIND VELOCITIES IN MPH
P_o = 28.00 in.

U.S. WEATHER BUREAU DATA

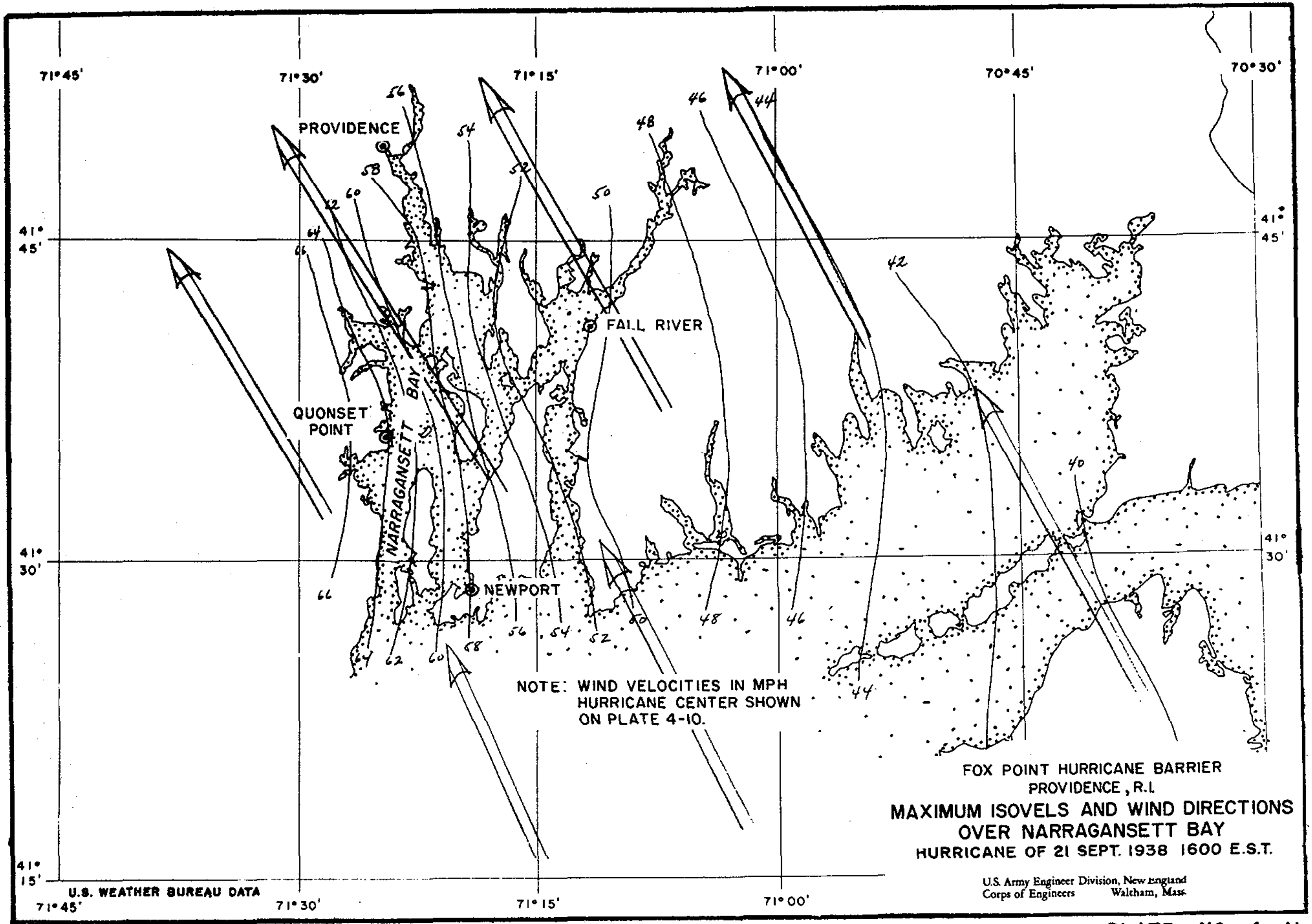
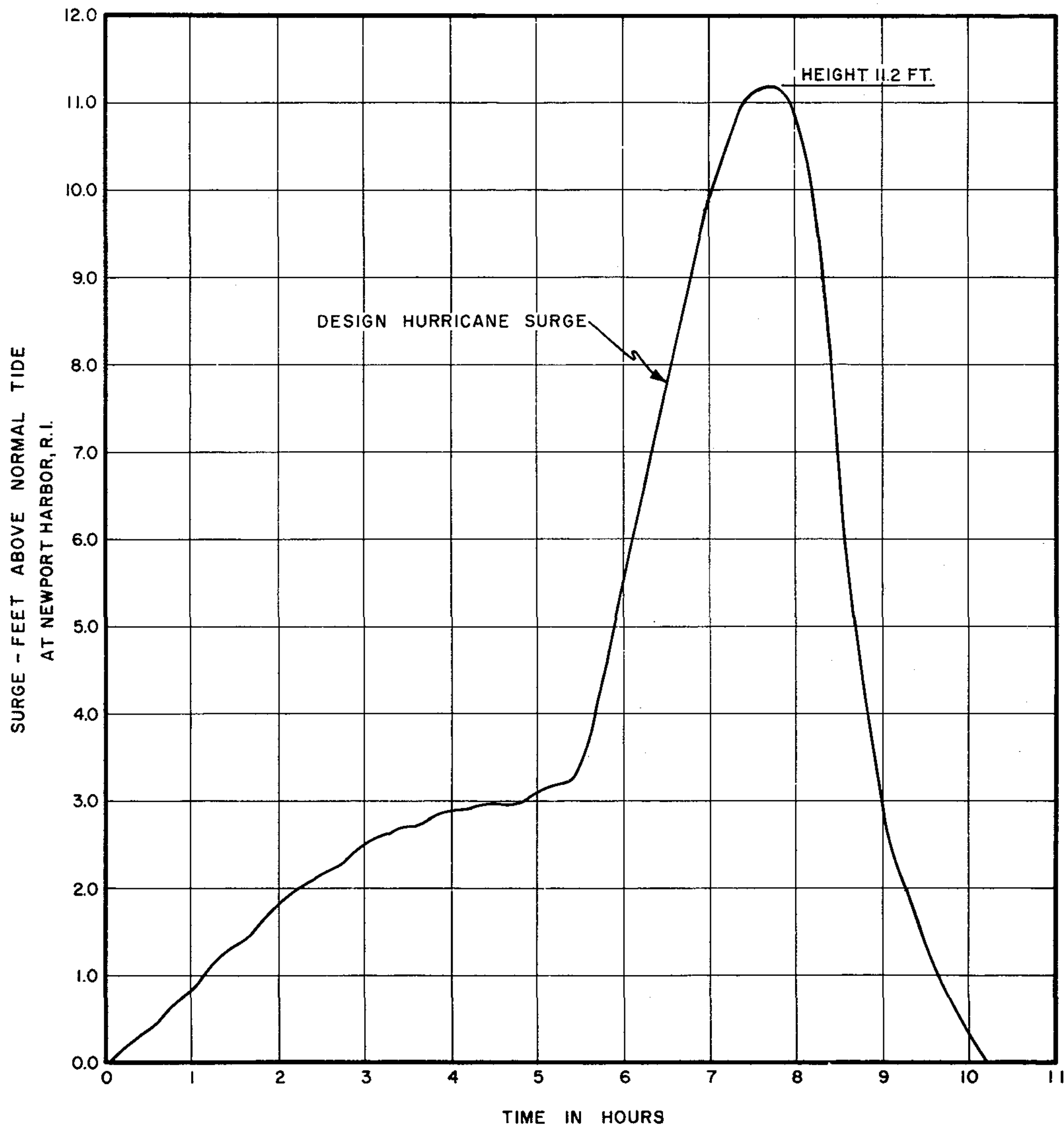

71°45'
71°30'
71°15'
71°00'
70°45'
70°30'
41° 45'
41° 30'
41° 15'
PROVIDENCE
FALL RIVER
QUONSET POINT
NARRAGANSETT BAY
NEWPORT
NOTE: WIND VELOCITIES IN MPH
HURRICANE CENTER SHOWN
ON PLATE 4-10.
U.S. WEATHER BUREAU DATA
FOX POINT HURRICANE BARRIER
PROVIDENCE, R.I.
MAXIMUM ISOVELS AND WIND DIRECTIONS
OVER NARRAGANSETT BAY
HURRICANE OF 21 SEPT. 1938 1600 E.S.T.
U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

PLATE NO. 4-11



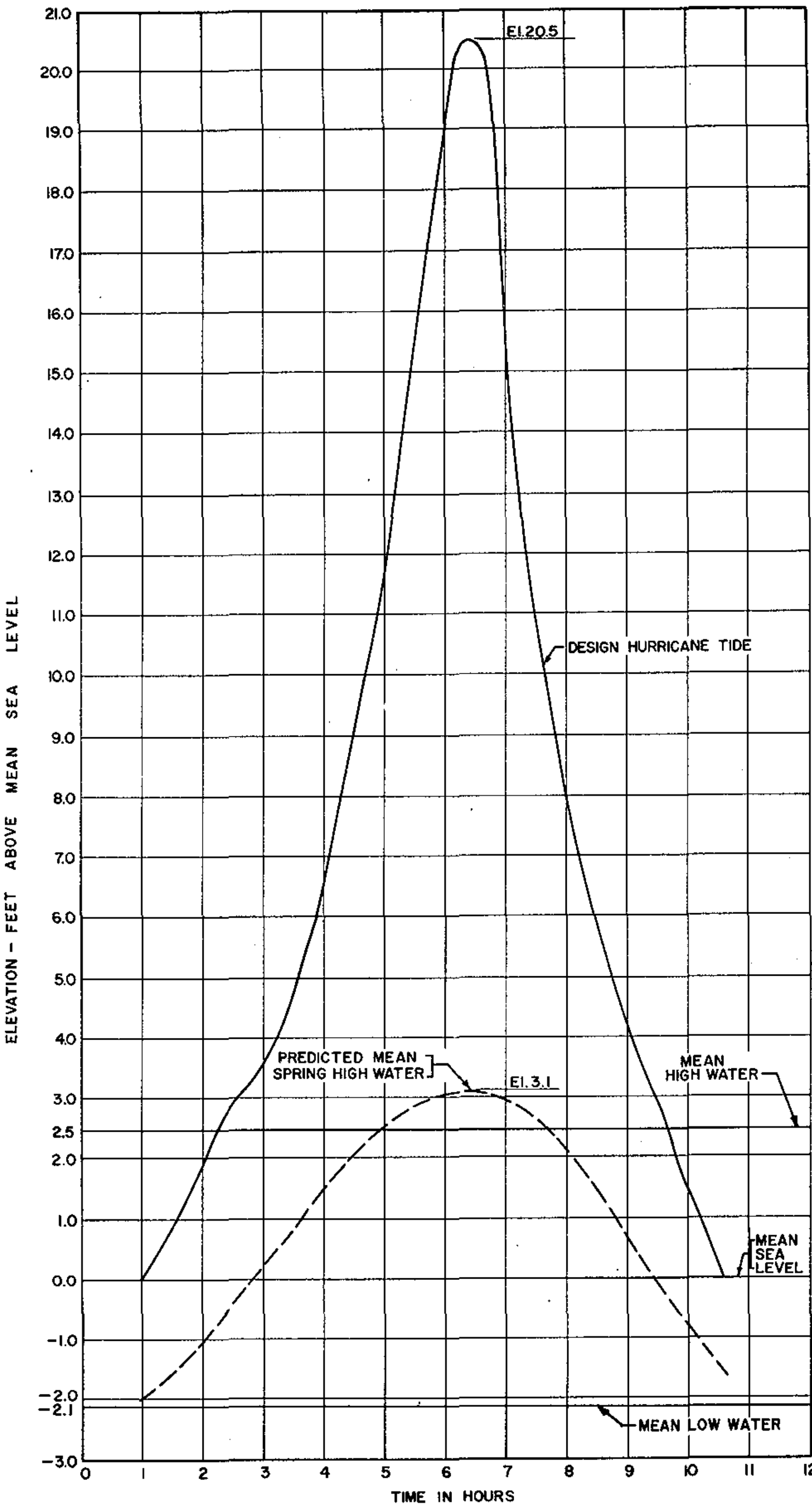
NOTE:
Design hurricane surge curve based on Texas A. & M. surge calculations for a design storm with a 40 knot propagational speed and with a track most critical to Narragansett Bay.

FOX POINT HURRICANE BARRIER
PROVIDENCE, RHODE ISLAND

DESIGN HURRICANE SURGE
AT
MOUTH OF NARRAGANSETT BAY

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

PLATE NO. 4-12



Design hurricane tide curve based on Texas A.&M. surge calculations for a design storm with a propagational speed of 40 knots and with a track most critical to Narragansett Bay. The peak of the surge is assumed to be coincident with the predicted mean spring high water

FOX POINT HURRICANE BARRIER
PROVIDENCE, RHODE ISLAND

DESIGN HURRICANE TIDE CURVE

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

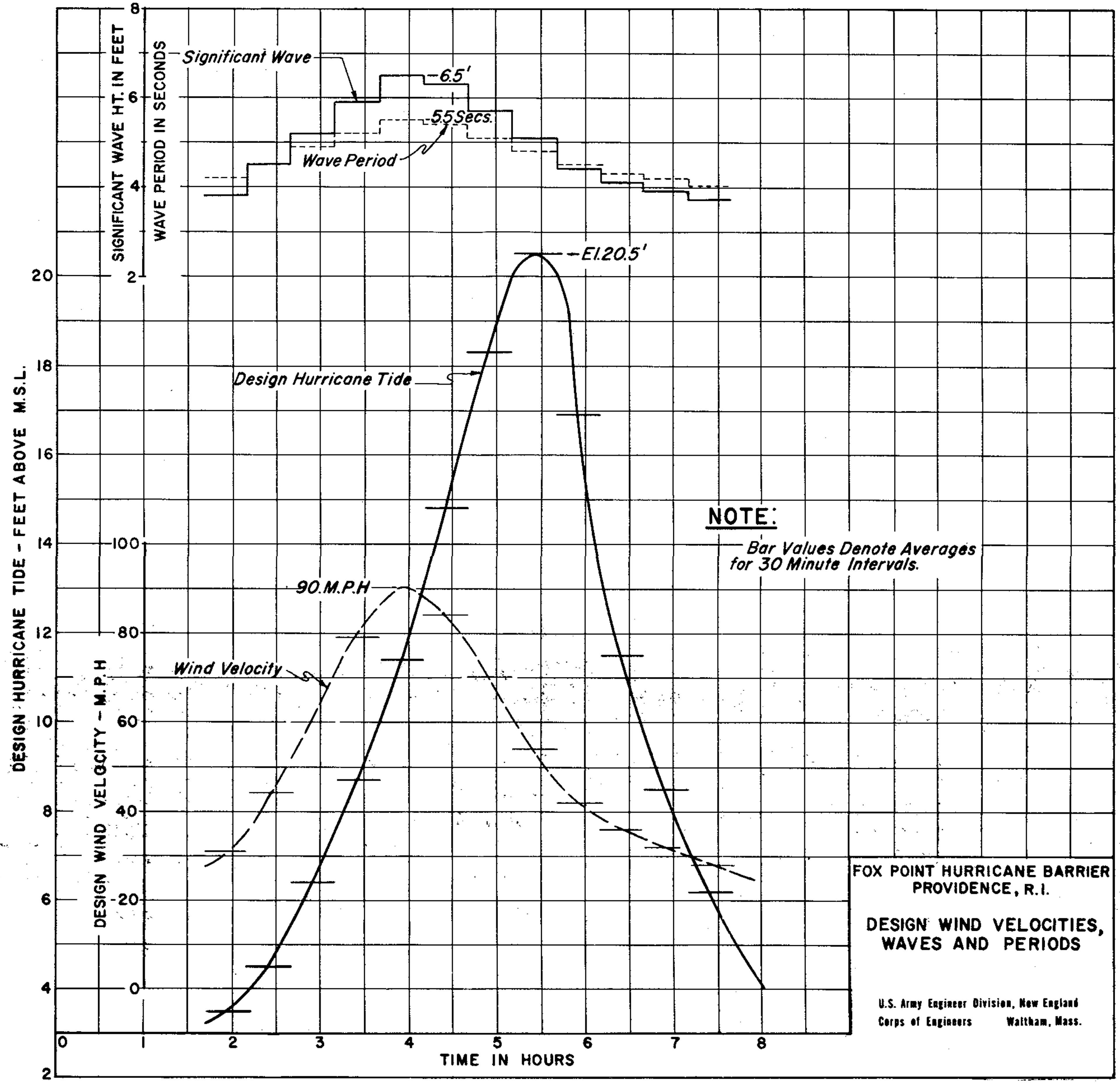

Significant Wave
-6.5'
5.5 Secs.
Wave Period
SIGNIFICANT WAVE HT. IN FEET
WAVE PERIOD IN SECONDS
-El. 20.5'
Design Hurricane Tide
NOTE:
Bar Values Denote Averages for 30 Minute Intervals.
90.M.P.H
Wind Velocity
DESIGN HURRICANE TIDE - FEET ABOVE M.S.L.
DESIGN WIND VELOCITY - M.P.H
TIME IN HOURS
FOX POINT HURRICANE BARRIER
PROVIDENCE, R.I.
DESIGN WIND VELOCITIES, WAVES AND PERIODS
U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

PLATE NO. 4-14

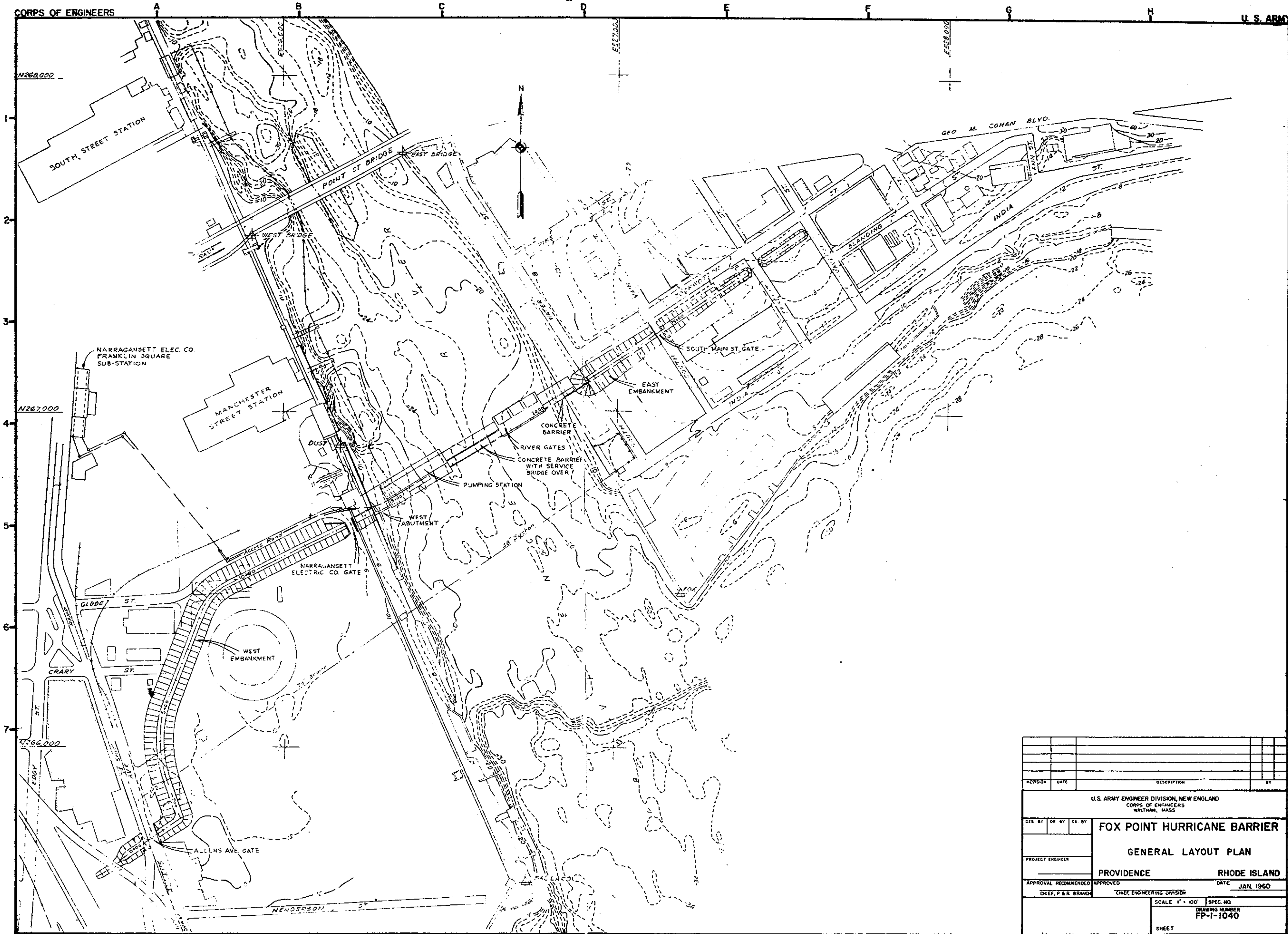

CORPS OF ENGINEERS
U. S. ARMY
N268,000
N267,000
N266,000
SOUTH STREET STATION
POINT ST BRIDGE
EAST BRIDGE
WEST BRIDGE
GEO M. COHAN BLVD.
INDIA ST.
BLANDING ST.
NARRAGANSETT ELEC. CO. FRANKLIN SQUARE SUB-STATION
MANCHESTER STREET STATION
SOUTH MAIN ST. GATE
EAST EMBANKMENT
CONCRETE BARRIER
RIVER GATES
CONCRETE BARRIER WITH SERVICE BRIDGE OVER
PUMPING STATION
WEST ABUTMENT
Access Road
NARRAGANSETT ELECTRIC CO. GATE
GLOBE ST.
CRARY ST.
EDDY ST.
WEST EMBANKMENT
ALLENS AVE GATE
HENDERSON ST.
REVISION
DATE
DESCRIPTION
BY
U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS.
FOX POINT HURRICANE BARRIER
GENERAL LAYOUT PLAN
PROVIDENCE
RHODE ISLAND
PROJECT ENGINEER
APPROVAL RECOMMENDED
CHIEF, P & R BRANCH
APPROVED
CHIEF, ENGINEERING DIVISION
DATE JAN. 1960
SCALE 1" = 100'
SPEC. NO.
DRAWING NUMBER
FP-1-1040
SHEET

PLATE NO. 4-15